Strategic Environmental Research and Development Program (SERDP)

Development of Ecological Indicator Guilds for Land Management

Research Project: CS-1114B

Executive Summary

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Anthony J. Krzysik

Prescott College
Phone: 928-777-2106
krzysika@cableone.net

Research Team:
H.E. Balbach, M. Brown, J.J. Duda, J.M. Emlen, D.C. Freeman,
J.H. and C.C. Graham, D.A. Kovacic, E.A. Sobek, M.P. Wallace, J.C. Zak

Background, Objectives, and Approach

Military training and testing lands must be efficiently and cost-effectively monitored to assess conditions and trends in natural resources relevant to training sustainability, ecosystem maintenance, and the timing and success of restoration efforts. Ecological Indicator metrics represent important land management tools for tracking ecological changes and providing early-warning detection of threshold impacts relevant to training/testing missions. The objective of this research is to develop Ecological Indicators based on ecosystem relevant criteria, multi-scale performance, and stress-response criteria, for the purpose of monitoring ecological changes directly relevant to biological viability, long-term productivity, and ecological sustainability of military training and testing lands. Three important capabilities of developed ecological indicators would be: 1) the ability to assess and monitor multi-scale ecosystem stressor effects independent of natural environmental variability and disturbance regimes; 2) their direct applicability to ecoregional contexts; and 3) the developed approaches, analysis, and modeling capabilities could be extended to any global ecoregion. The motivation is for military land managers and trainers to use Ecological Indicator Guilds as part of their predictive tool box, in conjunction with decision support systems and carrying-capacity or land management models, to initiate and balance management decisions concerning natural resources conservation, resource harvesting, scheduling training exercises, rest-rotation, or ecological restoration options.

Ecosystems consist of soil, primary producers (plants), and consumers (animals) in a given physiographic-continental setting, which includes geology and climate. Soils are functionally characterized by biological (microbes and animals), chemical, and physical attributes. On the basis of the experience of our research team and the literature, we selected seven Ecological Indicator Systems (EIs) that represented all three ecosystem components: **1) Habitat Characterization** (physiognomy, floristics, soil physical properties), **2) Soil Chemistry**, 3) Nutrient Dynamics, **4) Microbial Communities**, **5) Invertebrate Communities**, 6) Plant Physiology, including Developmental Instability, 7) Plant Community Spatial Interactions. Some of these major indicator system categories contain multiple EI subsystems. The EIs emphasized in **bold** were used to construct Ecological Indicator Guilds. Our working hypothesis was to statistically characterize the response of these EIs along a military training disturbance gradient.

Suites of environmental variables within EIs that analytically portray the disturbance gradient were called Ecological Indicator Guilds. Guilds have a long history of use for classifying biological organisms with similar ecological function or exploitation of resources (Root 1973, Holmes et al. 1979). However, guilds have also been used in a broader context to classify ecosystem use by amphibians (Krzysik 1998), forest cover and age classes (DeGraaf and Chadwick 1984), and for environmental management, assessment, and monitoring (Järvinen and Väisänen 1979, Hawkings and MacMahon 1989). In our research context, guilds will represent suites of environmental variables or species groups explicitly characterizing a disturbance gradient.

Nine research sites were selected in pine – scrub oak Sand Hills physiography of the uppermost Southeastern Coastal Plain at Fort Benning, Georgia. Three sites each were classified into HIGH, MEDIUM, and LOW disturbance classes. **High** sites are characterized by current extensive mechanized infantry training activities employing tracked tactical vehicles. **Medium** sites experienced past military training activities, but are currently only used periodically by foot soldiers. **Low** sites have never been subjected to military training activities, and are currently protected for a variety of natural resource and conservation values. Two sets of Low-Medium-High sites are in the Bonham Creek watershed, while the third set is in Sally Branch.

Fort Benning lies in the southwestern extreme of the Sand Hills, which extends to the northeast in a narrow arc in the uppermost portion of the Atlantic Coastal Plain, just below the Piedmont. The junction of the Piedmont and Atlantic Coastal Plain is identified by the "Fall Line", representing a small rocky rise separating the flat lowland expanse of the Coastal Plain and the rolling hill country of the Piedmont. The narrow arc of Sand Hills supports a number of Army and Air Force installations, including Fort Gordon (Georgia), Fort Jackson (South Carolina), and Fort Bragg (North Carolina). Therefore, land management lessons learned at Fort Benning are ecologically relevant and directly applicable to a number of important military installations.

Research Activities and Results

Development of Ecological Indicator Guilds

Figure 1 reviews our technical approach in this project, and **Figure 2** provides our analysis strategy and milestones.

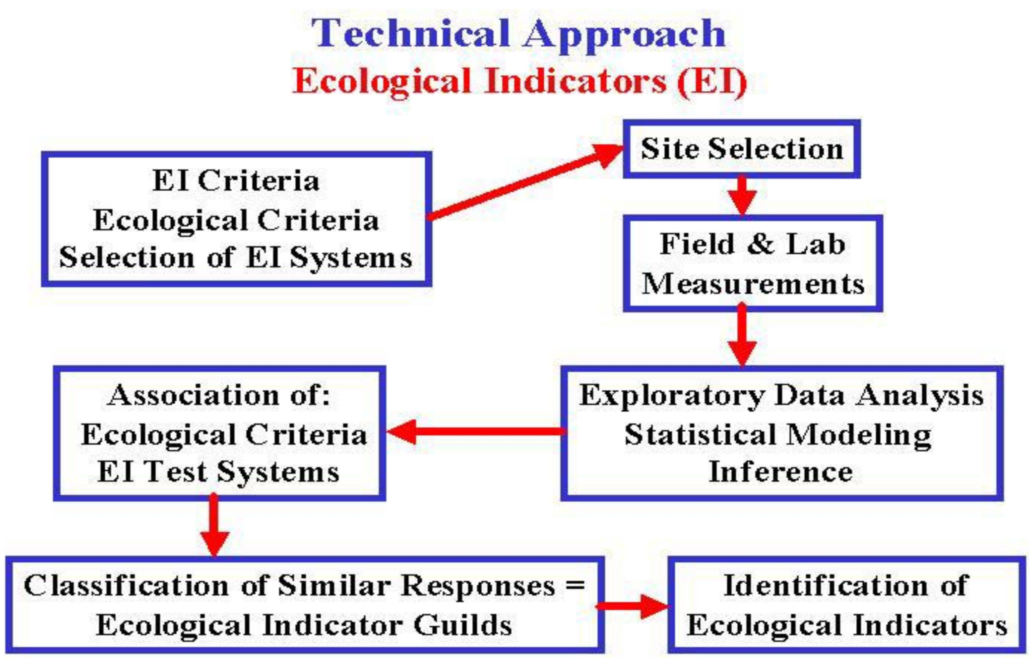

Figure 1. Technical approach for the identification of Ecological Indicators.

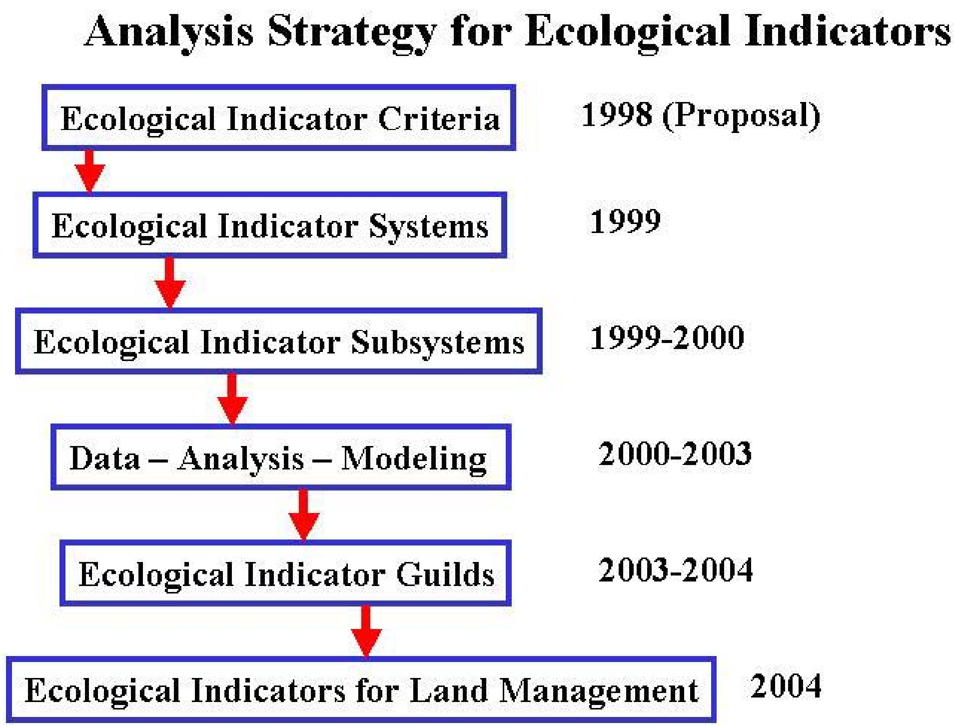

Figure 2. Analysis strategy and milestones for developing Ecological Indicator Guilds and Ecological Indicators.

Table 1 summarizes the development of Ecological Indicator Guilds from six Ecological Indicator Systems: General Habitat Variables, General Ground Cover, Woody Ground Cover, Soil Chemistry, Microbial Community, and Ground/Litter Ant Community. Discriminant analysis (DA) was performed on the six Ecological Indicator Systems to extract Ecological Indicator Guilds. DA weights the predictor variables (e.g., habitat variables) such that their linear combinations maximally distinguish (discriminate) among two or more predetermined groups or classes (Krzysik 1987). The well-known F-ratio tests the criterion for measuring class differences, sums of squares between groups versus sums of squares within groups: $F = SS_b/SS_W$. By rewriting sums of squares terms in the form of vectors of linear combinations of predictor variables, the matrix form reduces to:

$$\mathbf{V'Bv / v'Wv = \lambda}$$

λ represents the discriminating criterion, and the discriminant problem reduces to extracting the set of weights, or coefficients, that maximizes λ. In other words, covariance structure among groups is maximized, while minimizing within groups covariance. Discriminant Function 1 (DF1) maximally distinguishes the groups, DF2 represents the second best discriminant function, and so on. The number of derived discriminant functions is equal to one less than the number of groups in the analysis. DA has several desirable properties. When sample sites lie along a disturbance gradient, DA identifies the variables that best define the gradient. Because the method is sensitive to data matrix singularity, variables that possess high colinnearity with other variables, a common situation with environmental parameters, are a priori rejected from analysis (Tabachnick and Fidell 2001). Both direct (all variables entered simultaneously) and step-wise methods were used in the DA. Step-wise methods have been severely criticized (Green 1979), but their use in conjunction with direct analysis assists in assessing the robustness of analyses. In all the analyses presented here, both methods yielded identical patterns. The results of direct analyses were used to derive the discriminant scores that were plotted in the figures.

Detailed field methods for collecting habitat data can be found in Krzysik 2001 and Krzysik 2002.

Ecological Indicator System	Discriminant Analysis →	Ecological Indicator Guild
<u>General Habitat (11 variables)</u> A-Horizon Soil Depth Soil Compaction Soil Shear Strength Canopy Cover Basal Area Tree Density Tree Diameter (mean) Tree Size Distribution (densities of 4 Basal Area classes)		<u>General Habitat Guild (2 variables)</u> A-Horizon Soil Depth Soil Compaction
<u>General Ground Cover (7 variables)</u> Bare Ground (%) Litter (%) Forb Cover (%) Grass Cover (%) Legume Cover Woody Cover Woody Species Richness		<u>General Ground Guild (4 variables)</u> Bare Ground Woody Species Richness Forbs Grass
<u>Woody Ground Cover Community (34 Variables)</u> 34 Species Ground Cover (%)		<u>Woody Ground Guild (5 variables)</u> Rubus cuneifolius Rubus flagellaris Prunus angustifolia Quercus margaretta Quercus incana
<u>Soil Chemistry (6 variables)</u> Soil Organic Carbon Microbial Carbon Biomass pH Nitrate Ammonium Moisture		<u>Soil Chemistry Guild (4 variables)</u> Soil Organic Carbon Microbial Carbon Biomass Nitrate pH
<u>Microbial Community (4 variables)</u> Fungal Functional Diversity Fungal Total Activity Bacteria Functional Diversity Bacteria Total Activity		<u>Microbial Guild (2 variables in each season)</u> <u>May</u> Bacteria Functional Diversity Fungal Total Activity <u>November</u> Bacteria Total Activity Fungal Total Activity
<u>Ground/Litter Ant Community (27 variables)</u> 27 Species of Ants (abundance)		<u>Ant Guild (9 variables)</u> 9 Species of Ants

Table 1. Development of Ecological Indicator Guilds from Ecological Indicator Systems using Discriminant Analysis. Note the reduction in variables required to characterize the disturbance gradient.

Habitat Ecological Indicator Systems

Three Habitat Ecological Indicator Systems were effective in characterizing the disturbance gradient in discriminant space: General Habitat Variables, General Ground Cover, and Woody Ground Community. A fourth system, "Tree Community" was not as effective, indicating that the tree community has either not responded to, or has had insufficient time to respond to the environmental conditions produced by military training activities. A-Horizon Soil Depth and Soil Compaction (General Habitat Guild) were the most important habitat variables to discriminate among the three disturbance classes. Discriminant score means were very symmetrical in Discriminant Function 1 (DF1) space: Low sites = +2, High sites = -2, while Medium sites = 0. This was a remarkable and significant result.

The General Ground Cover Guild required both Discriminant Functions to separate sites in the disturbance gradient. Bare Ground and Woody Species Richness separated the High sites from less disturbed sites with DF1, while DF2 separated the Low and Medium sites on the basis of forb and grass cover.

Two species of brambles associated with sandy disturbed soils, two species of upland xeric oaks (sand post and bluejack), and a wild plum effectively characterized the disturbance gradient forming the Woody Ground Community Guild. Additional analyses are planned for this guild with the 2002 data, which has recently been completed.

The A-Horizon Soil Depth appeared very promising as a robust Ecological Indicator and motivated a comparison with the Savanna River Ecology Lab data set. SREL established 32 research sites at Fort Benning, 16 in "Lightly" used landscapes and 16 in "Heavy" used training areas. John Dilustro, who collected the soil data, predicted that their "Light" sites should correspond to our "Medium" sites, while the "Heavy" and "High" should be similar. It was remarkable to see how close our data matched the SREL data. Within each data set the difference between disturbance classes were statistically highly significant (ANOVA, $P<0.001$).

Soil Chemistry Ecological Indicator System

Four of the six variables: Soil Organic Carbon, Microbial Carbon Biomass, Nitrate, and pH were important in classifying the sites in the disturbance gradient. DF1 separated High from the less disturbed sites, while DF2 separated Low from Medium sites. The discriminant analysis for both May and November data produced very similar results, indicating that there were no seasonal effects.

Microbial Community Ecological Indicator System

Three of the four Microbial variables were effective in separating the sites in the disturbance gradient: Bacterial Functional Diversity and Total Activity, and Fungal Total Activity. Interestingly, the specific microbial variables and their respective contributions to Discriminant Functions were seasonally dependent, unlike the Soil Chemistry results. Additional analyses are planned.

Ant Community Ecological Indicator System

Twenty-seven ant species were collected over the three years of pit-fall trap sampling. Discriminant analysis on the entire data set identified nine species that were effective in discriminating the research sites in the disturbance gradient. DF1 separated the High from the less disturbed sites in all three years, while DF2 separated Low from Medium sites for all three years. Importantly, discriminant analyses conducted separately for each year yielded very similar results.

Dorymyrmex pyramicus and four species (*Aphaenogaster floridana, Paratrechina parvula, Pheidole sp., Camponotus castaneus*) closely associated with less disturbed sites effectively separated the High from the less disturbed sites along DF1. DF2 separated Medium from Low sites on the basis of three species (*Paratrechina parvula, Forelius pruinosus, Crematogaster minutissima*) more associated with Medium sites and two species (*Aphaenogaster ashmeadi, Brachymyrmex depilis*) more associated with Low sites. *Dorymyrmex pyramicus* comprised 96.7 percent of all individuals in the Ant Guild. It was of interest to see how the dominance of this species effected discriminant analysis results. Discriminant analysis was performed on the Ant Guild with this species absent from the analysis, and the identical pattern was retained. Apparently, the removal of the dominant species merely reinforced the importance in DF1 of the four species associated with less disturbed sites.

The Guild analyses presented here provides excellent foundations and support for the feasibility and value of this approach for military land management in a multiple-use context. These data were collected at and are directly relevant to nine sites in the Sand Hills physiography of Fort Benning, and must be validated in other Sand Hill sites both on and off the installation. After the reliability and applicability of the Ecological Indicator Guilds are verified in the Sand Hills, they require additional testing for robustness at other physiographic landscapes of the Southeast.

Invertebrate Communities

Species diversity (evenness and species richness) of ants was less in High disturbed sites than that in either Medium or Low disturbed sites. Density of ants was greatest in the High disturbed sites, apparently because lower canopy and ground cover increased soil temperature. The difference was due entirely to one species, *Dorymyrmex pyramicus*, which was very abundant at the High disturbed sites. This species occurs from Illinois to Argentinia and prefers higher nest temperatures (Wheeler 1910). Ground-dwelling ants, sampled by pitfall traps, were better indicators of disturbance than those collected in sweep-nets. Neither spiders nor orthopterans showed significant differences in diversity among disturbance regimes. Community composition of ants, spiders, and orthopterans varied with disturbance regime. Species adapted to open, sunny habitats dominated communities in the High disturbed sites. Distribution of arboreal ants was primarily dependent upon tree taxa, pine or oak. There was no obvious variation of arboreal ants among disturbance regimes.

A photographic key to the common ants of Fort Benning was completed, containing all the species that have been collected in pit-fall traps, net sweeps, and from tree bark -- 28 species, in 5 families. The key contains several detailed photos of each ant, and a list of diagnostic features.

A key to the common spiders of Fort Benning is also under preparation.

Nutrient Flux and Leakage

Calcium, magnesium, nitrate, and sulfate concentrations exhibited significant differences among site disturbance classes and sample dates. Lysimeter concentrations peaked in July on the High disturbance sites, while Low and Medium sites followed opposite trends for Ca, Mg, NO_3, and SO_4 in August and September of 2000. Lysimeter concentrations increased in mid-June 2001, and were low the winter of 2002. Sulfate levels increased in February 2002, while concentrations of Ca, Mg, and nitrate indicated increased soil solution nutrient concentrations later in June. Soil solution concentrations of Ca, Mg, nitrate and sulfate show consistent seasonal trends. However, soil solution nitrate is the only nutrient exhibiting consistently greater concentrations on the high disturbance level sites. While there is an apparent seasonal trend in nitrate, soil solution nitrate concentrations are extremely low on all sites, and do not appear to be a dependable indicator of disturbance.

Following disturbance, the ability of forests to fix and store carbon is reduced. Soil and litter carbon may be an important indicator of ecosystem biological integrity on military training sites. We hypothesized that soil carbon would be inversely proportional to the level of training intensity or soil disturbance. Soil carbon as a biological indicator may provide a relatively simple method to determine the levels of training intensity and past disturbance on a site.

Upland High disturbance sites were significantly lower in carbon than either Low or Medium upland sites. However, carbon levels in lowland sites did not differ significantly across the disturbance gradient. Forest litter carbon levels followed a similar trend. Although the findings are preliminary, they support our hypothesis that carbon levels are inversely proportional to the level of training disturbance.

Soil and litter samples from all sites were incubated in the laboratory to determine their mineralization and nitrification potential. Samples were collected in Feburary 2002, a time of low nutrient uptake, when soil nutrients would be immobilized in the fungal/microbial pool. Initial litter ammonium was variable and there were no consistent trends. After four weeks of incubation litter nitrogen levels were still quite variable exhibiting no consistent trends. Initial soil ammonium was also variable, and ammonium levels exceeded nitrate levels at all nine research sites. Initial soil nitrate levels were less variable than the litter values. After four week of incubation soil nitrogen levels exhibited significant trends across the disturbance gradient. The highest ammonium levels were found in the Low soils, while the lowest ammonium levels were found in the High soils. Soil nitrate levels were consistently lower at the Low sites and largest at the High sites. The average Low site nitrate concentration was significantly lower than the Medium site concentrations, and the Medium site concentrations were significantly lower than the High site concentrations. Less disturbed sites exhibit low nitrification levels with ammonium as the major form of inorganic nitrogen. Older ecosystem seres (i.e., more stable) typically utilize ammonium as the major source of plant inorganic nitrogen. Theoretically, uptake of ammonium is energetically more efficient as is plant uptake. Nitrate is the major form of inorganic nitrogen utilized by plants in more disturbed ecosystems. The differences between disturbance level inorganic N is a result of the different detrital food webs that dominate the sites. Less disturbed site have a more highly developed forest floor layer that favors lower decomposition rates and more fungal development. Fungi have the ability to translocate nutrients from the soil into the surface residue and to tolerate lower water potentials that occur in surface residues. The more disturbed sites, have lower carbon levels in the soil and poorer litter development. Bacteria appear to increase in more disturbed soils, where they may be more important in the decomposition of buried residues in closer contact with soil nutrients. These initial results indicate that soil mineralization potential may provide an accurate method of quantifying the intensity of soil degradation across a disturbance gradient. Additional sampling is required at different sites both within and outside of Fort Benning to assess the potential of this indicator.

Microbial Community and Loblolly Decomposition Rate

The highest amounts of Microbial Biomass Carbon for Bonham Creek upland sites in May were found in the Medium sites. The lowest mean levels were found in the High sites. Levels for the High Sally Branch site were similar to the Medium Bonham Creek sites. The lowland locations generally had the highest levels of microbial biomass carbon of any location. The higher levels in the lowland sites reflect the more favorable conditions for microbial growth, where the effects of fire and drought are mitigated in the lowland areas.

Soil nitrate levels were highest in the Medium and High disturbance sites compared with the Low sites of L1 and L2. However, nitrate levels at the Low Sally Branch site were similar to those found for the Medium and High disturbance sites. The lowest levels of extractable nitrate were associated with the Low sites in the Bonham Creek watershed. The pool size of nitrate is closely tied to plant uptake and soil moisture levels and is very dynamic. The higher levels in the Medium and High sites reflect the higher level of disturbance from fire and physical disturbance at these locations and the associated decline in plant uptake in response to disturbance.

Extractable ammonium levels were did not differ substantially among upland sites except for the Low Sally Branch site and one of the Bonham Creek Medium sites. Ammonium levels in the lowland locations varied considerable among locations with no discernable pattern in response to disturbance. Differences among sites probably reflect differences in mineralization rates coupled with plant and microbial uptake rates for this important nutrient at each location.

Weight loss of loblolly pine (*Pinus taeda*) needle samples examined at all six Bonham Creek sites averaged 25% after six months in the field. Mass loss was typically greater in the lowland areas. The uniform decomposition rates, irrespective of disturbance levels, reflect the impacts of the drought conditions that prevailed in the region during the first six months after field placement. Under drought conditions mass loss across sites was controlled primarily by abiotic constraints and was not influenced by site-specific impacts of disturbance to the microbial community.

Plant Developmental Instability and Physiology

Winged Sumac (*Rhus copallinum*)

The data discussed in the 2002 Annual Report refers to this species and not Tred-Softly (*Cnidoscolus stimulosus*). Developmental Instability (DI) was assessed with "Fluctuating Asymmetry", quantitatively reflecting the departure of a morphological attribute from bilateral symmetry (Graham et al. 1998). A Principal Components Analysis was used to reduce a large number of sumac leaf measurements to four Principal Components. The principal components were analyzed by Analysis of Variance (ANOVA) using years (1999, 2000, 2001, 2002) and sites (the disturbance gradient) as factors to assess statistical significance in DI. There was no significant difference among sites ($P=0.42$) for PC1, but there was significant differences among years ($P<0.001$), with DI being especially pronounced in 1999, the year with a severe drought. PC2 showed a significant difference among both years ($P<0.001$) and sites ($P<0.001$). The results of PC3 and PC4 closely paralleled the results for PC1. These results strongly suggest that drought had a greater affect than habitat disturbance on the DI of Winged Sumac, because PC1 expressed most of the variance in the fluctuating asymmetry of leaf morphology. Nevertheless, PC2 demonstrated that the specific weighed combinations of original leaf measures that made up this component may be an important metric for reflecting the disturbance gradient.

The results from ANOVA motivated a Discriminant Analysis, and the analysis was informative. In the drought years of 1999 and 2000, only the Medium sites were separated from the Low and High sites, which were similar. However, in the normal precipitation years of 2001 and 2002 Discriminant Function 1 (DF1) readily separated the three disturbance classes. The separation was particularly evident in 2002. The results of Discriminant Analysis were very clear in the separation of years. DF1 effectively separated all four years, with 2002 being very different than the others, and importantly a gradient in the discriminant scores was evident. DF2 also separated the four years, with the greatest drought year clearly isolated in discriminant space. DF3 strongly separated 2000 and 2001, as was clearly also shown in the Analysis of Variance. More exploratory data analysis will be conducted on these Indicator Systems.

Bigroot Morningglory (*Ipomoea pandurata*)

Morningglory was evaluated for DI and physiological stress along the disturbance gradient. DI was also evaluated using Fluctuating Asymmetry and ANOVA as discussed above. DI was higher in both the Low and High sites compared to Medium sites, but significance was borderline ($P=0.078$). DI increased as the proportion of bare ground ($P<0.028$) and the cover of conspecifics ($P<0.015$) increased.

Net photosynthesis of morningglory was higher at the High sites compared the both the Low and Medium sites ($P<0.001$). Net photosynthesis increased as total plant cover increased ($P<0.01$), but declined as the percent of bare ground increased ($P<0.003$). Plants at the Medium sites had lower transpiration rates than plants at the Low and High sites (overall: $P<0.001$). Transpiration was highest at low plant cover ($P<0.007$), and decreased as the proportion of bare ground increased ($P<0.001$).

Important Findings and Conclusions

Important Ecological Indicator Guilds (EIGs) have been developed that characterize the disturbance gradient in the Sand Hills of Fort Benning, Georgia. The General Habitat Guild consists of two indicators (A-Horizon Soil Depth and Soil Compaction) that not only closely and clearly characterize the entire disturbance gradient, but are easily measured and possibly reflect important underlying ecological processes. Other EIGs identified are: General Ground Cover, Soil Chemistry, and the Ground/Litter Ant Community. Preliminary analyses indicated that the Woody Ground Cover Community and Microbial Community also appear promising. Plant Developmental Instability and Physiology will also be assessed in the Guild context. This Ecological Indicator system shows promise at assessing the effects of drought and fire on ecosystem attributes.

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